

Female Reproductive Function in Areas Affected by Radiation after the Chernobyl Power Station Accident

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This paper reports the results of a comprehensive survey of the effects of the accidental release of radiation caused by the accident at the Chernobyl nuclear power station in April 1986. The accident and the resulting release of radiation and radioactive products into the atmosphere produced the most serious environmental contamination so far recorded. We have concentrated on evaluating the outcomes and health risks to women, their reproductive situation, and consequences for their progeny. We have concentrated on two well-defined areas: the Chechersky district of the Gomel region in Belorussia and the Polesky district of the Kiev region in the Ukraine. A number of investigations were carried out on 688 pregnant women and their babies, and data were obtained from 7000 labor histories of the development of newborns for a period of 8 years (3 years before the accident and 5 years after it). Parameters examined included birth rate, thyroid pathology, extragenital pathology such as anemias, renal disorders, hypertension, and abnormalities in the metabolism of fats, complications of gestation, spontaneous abortions, premature deliveries, perinatal morbidity and mortality, stillbirths and early neonatal mortality, infections and inflammatory diseases, neurological symptoms and hemic disturbances in both mothers and infants, trophic anomalies, and biochemical and structural changes in the placenta. Several exogenous, complicating influences were also considered such as psycho-emotional factors, stress, lifestyle changes, and others caused directly by the hazardous situation and by its consequences such as treatment, removal from affected areas, etc. The results allow us to conclude that health of mothers, fetuses, and children were significantly influenced by the radiation, with adaptational and pathological abnormalities of various organs and body systems of pregnant women and children. Although the female reproductive system itself remains relatively intact, the decrease in compensatory-adaptive mechanisms of mothers and fetoplacental disorders cause long-term or chronic diseases in the newborns. It is suggested that special attention is paid to possible prophylaxis and to treatment of groups at risk in order to reduce hazardous consequences of such accidents and to preserve the health of future generations.

Introduction

The accident at the Chernobyl nuclear power station on April 26, 1986, is the most serious ecological catastrophe of the twentieth century. At present its consequences are still being assessed and discussed, but the results of investiga-

tions by different expert groups are rather contradictory. Unlike analogous accident in other countries, the Chernobyl disaster is characterized by certain peculiarities such as release of products of nuclear fission from the nuclear reactor of the power station; leakage of radionuclides in stages; and influence of hazardous consequences of the accident on large groups of the population. More than 100,000 square km of territories in the Ukraine, Belorussia, and Russia were polluted by radiation.

The disaster has posed new problems that have not previously been encountered because of the intensity and the peculiarities of the radiation and other related, coexisting factors such as stress, population migration, changes in nutrition, etc. The complete lack of experience world-

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wide in tackling these problems has necessitated new approaches to the evaluation of health risks to the population, and there is particular concern about pregnant women and their progeny.

Materials and Methods

A survey of 688 pregnant women and their babies under medical supervision was carried out, and this included epidemiological, clinical, and laboratory investigations. In addition, we performed a retrospective analysis with specialized evaluation of 7000 pregnancies, paying particular attention to their labor histories and the developmental course of the newborn children. Women from two different districts were examined, each district having a single, central regional hospital in which all the women in the survey delivered their babies. The retrospective analysis was based on the case records and all relevant documents from these two hospitals. A mobile team of doctors from our Research Centre in Moscow assisted with the analysis of the data. This survey extended over an 8-year period from 3 years before the accident to 5 years after. There were enough data collected from the survey to allow assessment of various health indexes including the course of the pregnancies, events in labor and at parturition, and the condition of the neonates. The population studied came from areas affected by the escape of radiation.

The areas selected for the investigation were under constant control because of contamination with radiation, and various degrees of pollution with radionuclides were detected. These areas were the Chechersky district of the Gomel region in Belorussia and the Polesky district of the Kiev region in the Ukraine. The average total dose of the patients examined was estimated to have been 7.5–10 bar. Analysis of the social and ecological factors that are typical for these districts did not reveal any significant difference between them, and the populations were homogeneous throughout the period of the investigation, being

similar before and after the accident. Both districts under investigation are agricultural areas with similar lifestyles and work conditions. There are no large industrial enterprises, cellulose or chemical plants, or other hazardous manufacturing factories.

An important finding was that 53% of the women and children under examination in the Polesky district of the Kiev region lived in areas where the radioactive pollution of the soil was greater than 20 kCi/km² (740×10^6 Bq/m²), whereas only 20% of the women living in the Chechersky district of the Gomel region were exposed to this level of soil pollution. The largest group of the investigated population lived in territories with 10–20 kCi/km² (370–740 MBq/m²) of soil pollution. The following population studies were performed: *a*) Polesky district: 1/1/90, female population 11,809, with 6,284 fertile women; 1/1/91, female population 11,500, with 4,436 fertile women; *b*) Chechersky district: 1/1/90, female population 13,800, with 7,300 fertile women; 1/1/91, female population 14,514, with 7,860 fertile women.

For most of the period of the survey, the rate of migration of pregnant women was low, being similar to the rest of the country (approximately 1–2%). Systematic emigration from Polesky district began in 1990–1991. The health indexes changed significantly following the accident, and these changes are discussed in this paper.

Results

Birth Rate

The birthrate decreased after the accident from 17.1% to 14.4% in Chechersky district and from 17.0% to 11.2% in the Polesky district. The lowest overall rate was recorded in 1987, and this was followed by a 2-year period of increasing birth rate, then another drop in 1990 to 14.2% in Polesky and 11.1% in Chechersky (Fig. 1). The dynamics of the changing birthrate were a reflection of the process of population migration, the wide use of contraception, the increased number of induced abortions, and the evacuation at a later date from the areas under radiation control.

The ages of the majority of pregnant mothers in the years before and after the accident ranged from 20 to 29 years. In the Chechersky district, 76.2% were in this age group before the accident and 71.8% afterwards. In 1990 there was an increase in the proportion of pregnancies occurring at a younger age: 8.8% of pregnant women before the accident, and 19.6% in 1990, were 19 years old or younger. The relative proportion of primiparas and multiparas remained the same, the prevalence of multiparas being 6–8%, which is typical of the modern population.

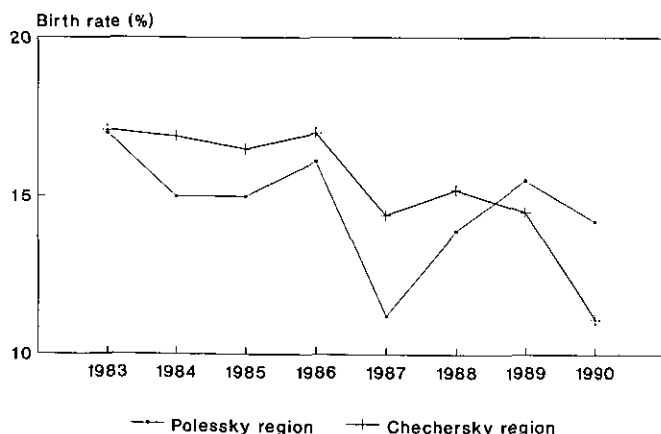


FIGURE 1. The changing pattern of birth rates in the Chechersky area of Belorussia and in the Polesky area of the Ukraine before and after the Chernobyl accident.

Extragenital Pathology

The rate of extragenital pathology during pregnancy increased in the years after the accident from 23.1% in 1982 to 33.9% in 1990 in Chechersky and from 7.1% to

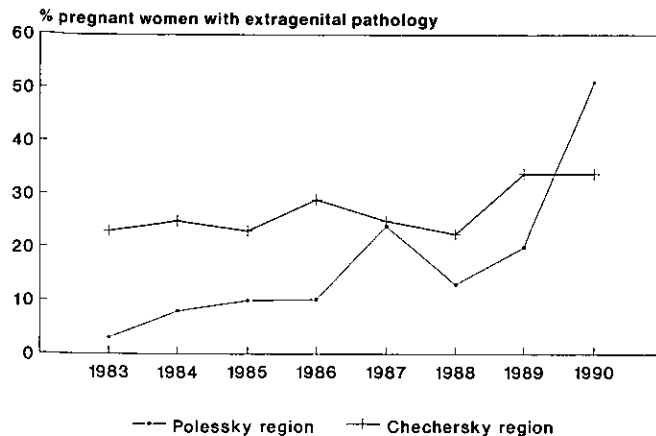


FIGURE 2. The increasing incidence of extragenital pathologies in pregnant women in the vicinity of Chernobyl.

51.2% in Polesky over the same period (Fig. 2). The main pathologies in both districts were anemia of pregnancy, renal disorders, transient hypertension, and abnormalities of fat metabolism.

Special attention was paid to thyroid pathology because the radioisotopes of iodine affected large sectors of the population, including persons suffering from endemic goiter, that did not receive any prophylactic iodine treatment either before or after the accident. In the screening program, examination of the pregnant women of Polesky district in 1989 revealed 29.4% with degree I-III hyperplasia of the thyroid gland, and 57.5% in 1990 (25% with degree II and III hyperplasia).

Psychological Disorders

In addition to the exogenous substances that had a direct pathological effect on the health of the pregnant women and mothers, psycho-emotional factors were also very important. Immediately after the accident, the living conditions were extremely hazardous to health and life threatening. After the initial phase there was a more chronic period of extremes of environmental conditions associated with many additional stress factors such as changes in lifestyle and migration to different areas. Assessing the psychological effects of the accident revealed that the majority of pregnant women and mothers feared for the life and health of their children and families. Neurotic disorders were discovered in 40.4% of cases. In 1991, 28.8% of the patients had transitory hypertension. Typically among the mothers in these regions there was a feeling of uncertainty, lack of will power, a decrease in emotional expression and reduced capacity for adaptation. Psychological investigation with the Lusher test substantiated the clinical assessment data: 75% of women from the polluted territories displayed anxiety and among these 21% suffered from deep depression and feelings of alarm. Outside of the polluted area, 45% of women had anxiety and 5% had deep depression.

Obstetric Pathology and Abnormalities of Labor

The patients in the survey were found to have an increased incidence of obstetric disorders during gestation and labor coexisting with the above extragenital diseases. The incidence of early toxemia increased by a factor of 2-3 in both districts, being highest in 1988-89, and the risk of early and late spontaneous abortion increased by a factor of 2-2.5. The frequency of late toxemia in Polesky increased from 6.2% in 1983 to 15.1% in 1990 and in Chechersky from 15.7% in 1982 to 21.8% in 1988. The predominant feature of late toxemia was degree I and II nephropathy. The rate of premature delivery remained substantially unaltered in both districts, being 2.4% in Chechersky and 5.9% in Polesky. However, the incidence of postmaturity increased by a factor of 1.5-2 in both regions following the accident.

In Chechersky there was a progressive increase in abnormalities of labor including both prolonged labor due to weak maternal effect and precipitate labor. In Polesky there was little change until 1990, when the incidence of precipitate labor increased.

Postnatal Complications

The main complication in the postnatal stages was anemia, which increased in incidence progressively in the years after the accident. The increase in rates of incidence between 1983 and 1990 were from 9.1% to 15.2% in Chechersky and from 1.1% to 9.3% in Polesky. There was no increase in the incidence of pathological blood loss at delivery (>400 mL) in the years after the accident.

Perinatal Mortality

An analysis of the perinatal mortality is an important factor in the evaluation of the medical consequences of the Chernobyl disaster (Fig. 3). In the first 3 years after the accident, perinatal mortality in the Chechersky district decreased from 11.5% to 7.3% due to a reduction in both fetal and neonatal deaths. In the Polesky district there was an increase in perinatal mortality over these same 3 years from 15.1% to 17.8%, the majority of the deaths and the increase in mortality being accounted for by the large numbers of stillbirths. In 1990 there was an increase in perinatal mortality in both districts, and for the first time over the entire survey the majority of the deaths occurred postpartum in the early neonatal period.

The highest recorded level of perinatal mortality was 37.4% in the Polesky area in 1987 when the stillbirth and early neonatal mortality rates were 20.6% and 16.8%, respectively. The most frequent overall causes of perinatal mortality, in order of frequency, both before and after the accident, were asphyxia, congenital abnormalities, and respiratory distress. Although congenital abnormalities remained the second most common cause of perinatal mortality, their incidence increased by a factor of 2 following the accident. Congenital heart disease was a common

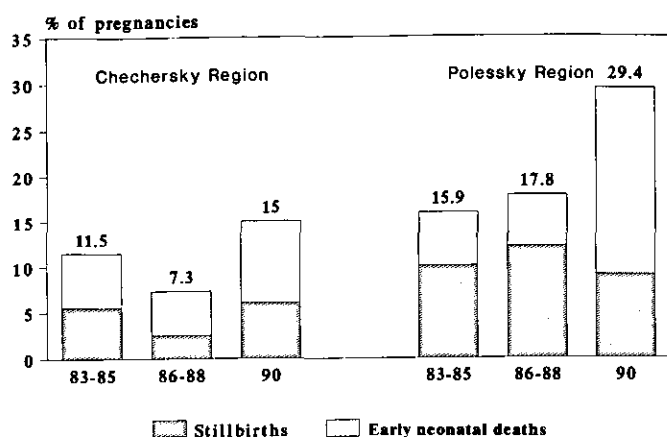


FIGURE 3. Perinatal mortality before and after the Chernobyl accident.

finding and frequently coexisted with esophageal atresia, anencephaly, hydrocephaly, and cases of multiple malformations. Examination of the causes of perinatal mortality in the Chechersky district alone revealed a different pattern of distribution. Before the accident, birth trauma was the most frequent cause, followed by respiratory distress then congenital abnormalities. After the accident, respiratory distress was first, congenital abnormalities second, and birth trauma third. In the years after the accident in both districts there was an increase in the mortality rate of premature neonates.

Condition at Birth

The study did not reveal any differences in the weight/length ratios of the newborns before and after the accident, the average weight being 3499 ± 29 g. However, anthropometric data indicated an increase in the number of large fetuses (>4000 g) and a decrease in the number of low birth weight babies (<2500 g). The incidence rates were from 14.1% to 17% for large fetuses and from 4.33% to 2.3% for low weight babies. However, the trends were reversed in 1990, when there was a reduced number of large fetuses and a greater number of low birth weight babies.

The number of newborns with an Apgar score of 7 or less increased steadily over the whole period (Fig. 4). In Chechersky, before the accident, 19.5% of newborn babies had an Apgar score of 5-7, and this increased to 69% after the accident. The average score was 6.7 in Chechersky and 7.5 in Polessky.

Neonatal Morbidity

The incidence of neonatal morbidity increased 3-fold in Polessky and 2-fold in Chechersky following the accident (Fig. 5). The diseases recorded were hypoxia, congenital abnormalities, respiratory distress, infections, and inflammatory disease. Fetal and neonatal hypoxia was twice as common. Respiratory distress increased 7-fold in

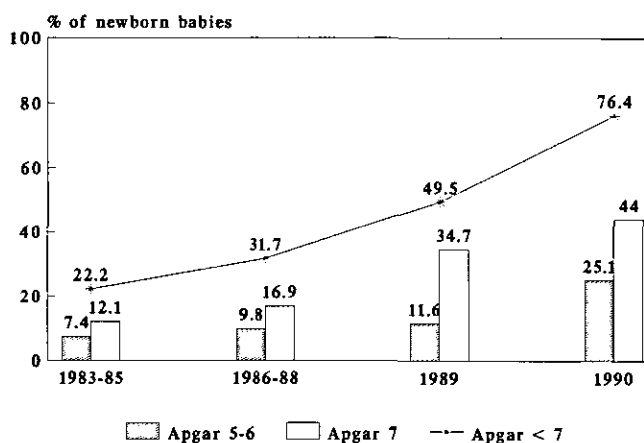


FIGURE 4. Apgar score of newborn babies before and after the Chernobyl accident.

Chechersky and by a factor of 2 in Polessky (Fig. 6). The incidence of congenital abnormalities in neonates was virtually unchanged at 5-6% in Chechersky, but there was a marked increase in Polessky from 6.9% to 24%, which exceeded the rates in all other parts of the country. Skeletal abnormalities were most frequently detected. Neurological effects were detected in 45% of newborn in both districts in 1990, and these were more prominent when hypoxia and respiratory distress coexisted.

Hemorrhagic syndromes increased in frequency 9-fold and were manifest as alimentary hemorrhage causing melena or subcutaneous hemorrhage. The pre-accident incidence was 0.5-1.0%, increasing to 4.4% (Polessky) and 5.1% (Chechersky) in 1990. Hematological disorders in general increased among the whole population of the polluted territories with combined defects in the red and white cell series and platelets (Fig. 7).

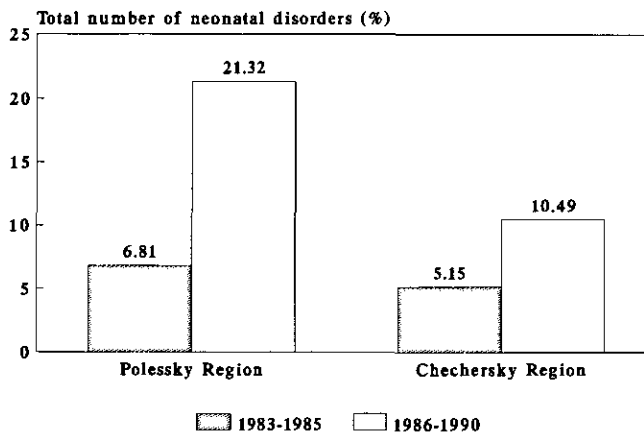


FIGURE 5. Neonatal morbidity showing the total number of disorders in neonatal infants and the changing pattern following the Chernobyl accident.

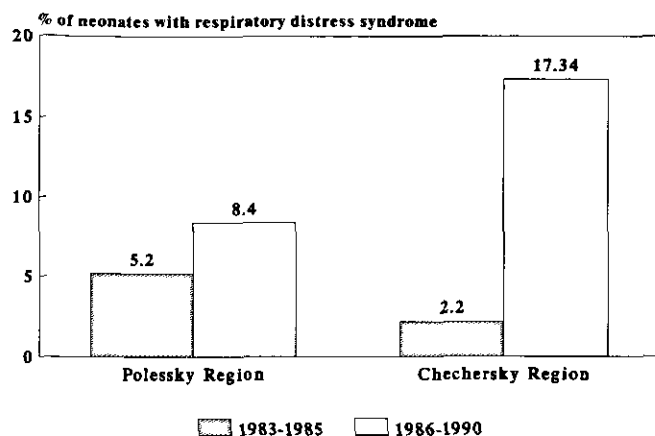


FIGURE 6. The incidence of respiratory distress syndrome in neonates before and after the Chernobyl accident.

The number of circulatory disorders and metabolic defects increased. High arterial blood pressure (90–100 mm Hg) was detected in 46% of the children examined. Special attention was paid to the children with arterial hypertension from the first day of life, which was discovered in 32% of cases and was usually associated with disturbances of antenatal development such as paratrophy (56%), hypotrophy (31%), and hypoplasia of hematopoietic tissue. One-third of these newborn babies also had evidence of eructation. The combination of these disorders may be regarded as antenatal hypothalamodiencephalic disturbances.

Health Index Categories

The investigations of the medical conditions of the mothers and their newborn babies produced four different categories grouped according to their health indices as

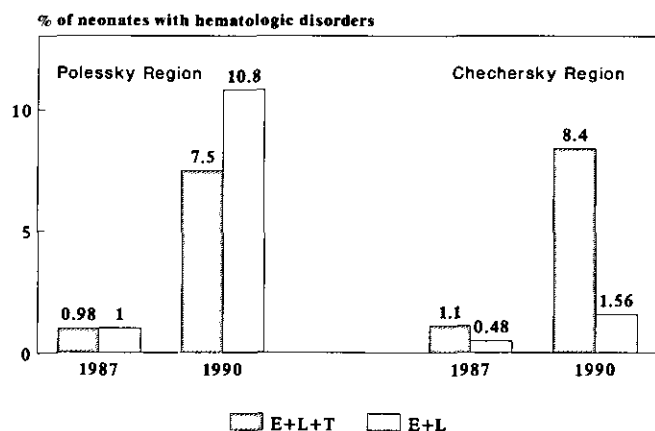


FIGURE 7. The changing pattern of hematological disorders in neonates born in the vicinity of Chernobyl. E, erythropenia; L, leukopenia; T, thrombocytopenia.

follows: group 1, mother and newborn are healthy, and pregnancy and labor proceeded without complications; group 2, newborn baby is healthy; mother has extragenital pathology and/or complicated pregnancy and labor; group 3, newborn baby has transient disorders at birth; group 4, newborn baby is ill and the pathological processes extend beyond the early neonatal period.

In the years following the accident, there was a general decline in the health index with a 3-fold reduction in the number of children in group 1 in comparison to the general population. Simultaneously, the number of ill children increased by a factor of 2.4 in both polluted areas, these children suffering from somatic disorders (46%), neurological disorders (7.4%), hematological disorders (59%), and infectious diseases (15.6%). A combination of the pathological disorders was seen in 28% of the children.

The children were followed-up for their first year of life and this confirmed the abnormalities tentatively diagnosed in the neonatal period: trophic disturbances (in 53% of children examined; Fig. 8), hypothalamo-diencephalic disorders in the form of neuro-vegetative diseases (30%), high morbidity rate: increased frequency of diseases especially inflammatory conditions of respiratory and urinary systems (20%).

Hypotonia was discovered in 57% (Polesky) and 41% (Chechersky) of children. Psychomotor development was arrested in 38% of children, resulting in a decrease in emotional reactions, signs of asthenia with reduced activity, and delay in the formation of stato-kinetic functions. Therefore, as a result of the significant increase in somatic and psychoneurological disorders in the children in their first year of life, the health index at 1 year was less than that of neonates, and at this stage was 6.5 times lower than the general population.

Systemic Abnormalities

Specific system-oriented tests provided data on the functioning of different organs in pregnant women, fetuses and neonates.

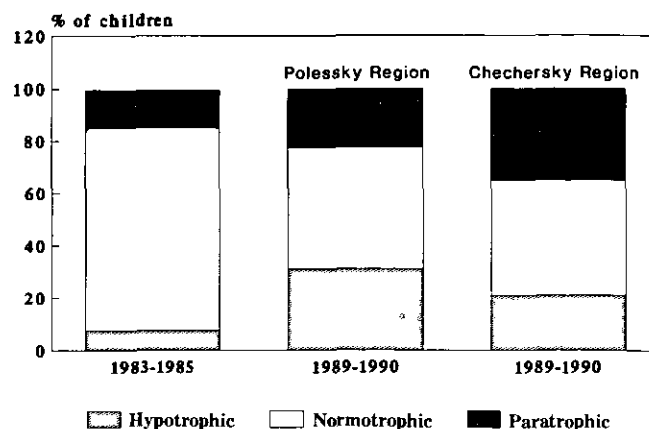


FIGURE 8. The physical development of infants in their first year of life.

Thyroid Function Tests. Pregnant women in both districts, especially in Polesky, had declining thyroid function as revealed by serum levels of T_3 (triiodothyronine), T_4 (thyroxine), and TBG (thyroxine binding globulin). The average blood T_3 levels were 2.2 nmole/L (Polesky) and 2.7 nmole/L (Chechersky), the normal level being 3.2 nmole/L. The functional activity of thyroxine is estimated from the ratio of T_4 to TBG levels, the normal being 260–300. The ratio was significantly lower than normal (173) in Polesky, and this was due to a rapid increase in TBG, which was more pronounced in Polesky. The severity of the thyroid dysfunction depended on the degree of pollution in that area.

Immunoglobulins. The absolute serum levels of IgA and IgG were decreased in pregnant women in Polesky, and IgM was increased in Chechersky. However, in relative terms, the normal levels of IgM in Polesky were high in relation to the IgA and IgG levels. These results suggest impaired immune mechanisms, especially in Polesky. In addition, 80% of the pregnant women in Polesky had increased levels of C-reactive protein (>1 mg/dL), reflecting the destructive and inflammatory conditions present in these women.

Blood Changes. The formed elements in blood and intercellular structures in plasma were investigated by electron microscopy because the hematopoietic tissue is the most sensitive to ionizing radiation. Large aggregates of platelets with other blood cells were detected, which may have caused intravascular coagulation in the microcirculation. The neutrophils showed clasmotosis of the cytoplasm, which may be associated with defective inflammatory and phagocytic activity. There was also accumulation of neutrophils around nuclear fragments in the blood.

These observations on the neutrophils may be connected with radiation effects at the cellular level.

The peripheral blood monocytes appeared highly activated at the electron microscopic level. Similar changes were seen at the site of fetal detachment in patients with fetoplacental insufficiency.

Placental Abnormalities. Ultrasonic examination of fetuses did not reveal any significant abnormality. However, the thickness of the placenta was abnormal at all gestational periods examined, and the magnitude of this was related to the level of pollution. At 19–20 weeks of gestation and at the end of the third trimester, the thickness of placentas from the polluted areas exceeded normal values by 35.7% and 23–27%, respectively. In a 12-point scale of placental abnormalities, the 19- to 20-week placentas differed from normal by 4 points and the 39- to 40-week placentas differed by 10 points. The changes in the structure of the placenta were due to increased involutional and dystrophic changes, which may be related to activation of its barrier function.

Serum Hormones. Hormones in the blood of pregnant women were measured by radioimmunoassay and disclosed a number of peculiarities of the endocrine function of the placenta and fetoplacental complex. Patients with normal pregnancies had elevated levels of serum placental lactogen, and the highest levels were detected in patients in Polesky. In late pregnancy, the serum placental lactogen was 2–2.5 times higher than normal, and this may be due to the increased placental thickness. At this time the serum estriol levels were becoming lower than normal over the second half of pregnancy, suggesting fetoplacental deficiency and a worsening of the condition of the fetus (Fig. 9).

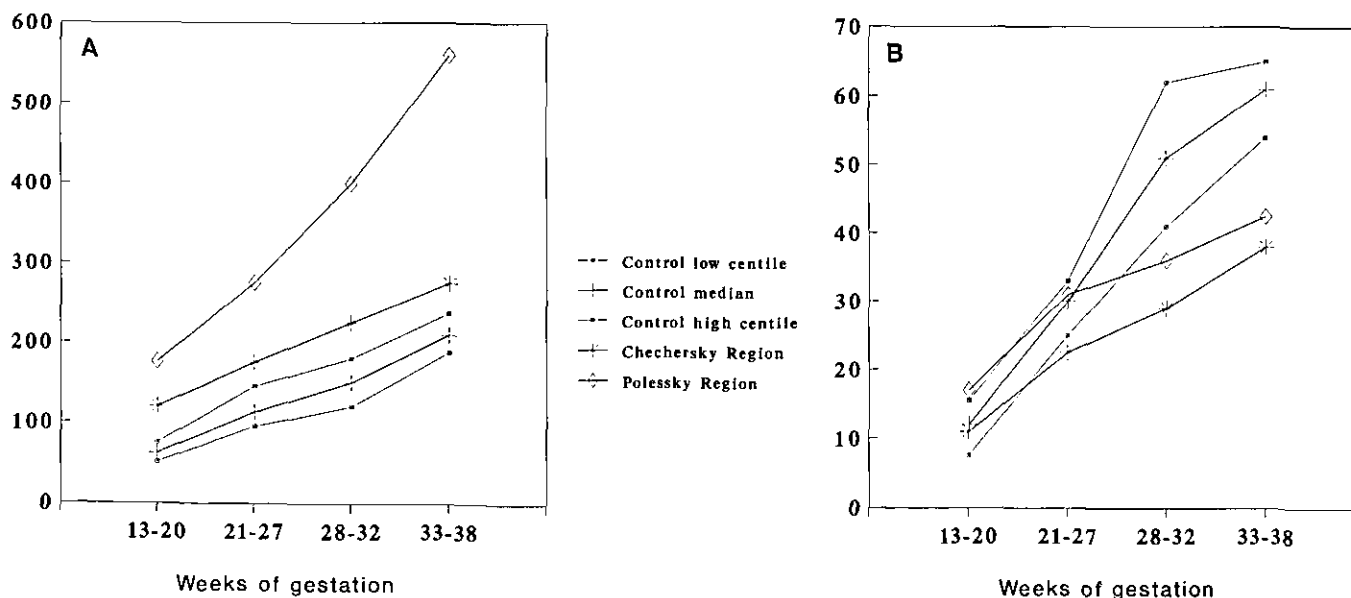


FIGURE 9. Maternal blood levels of placental hormones during pregnancy used as a measure of placental function. (A) Placental lactogen, (B) estriol.

Placental Proteins. Synthesis of specific proteins is an important role of the placenta, and these often have immunosuppressive activity on maternal factors, which is required for preservation and normal development of the fetus. Such proteins are trophoblastic β_2 -globulin (TBG), α_2 -microglobulin of fertility (AMGF), and placental α_1 -microglobulin (PAMG-1). Serum TBG concentration was decreased in 75% (Chechersky) and 25% (Polessky) of women. Decreased levels of AMGF, which is synthesized by the decidua, were detected in 50% of second trimester and 65% of third trimester women. The PAMG levels were not different from the controls. The changes in placental protein levels may effect the functional activity of the placenta.

Placental Changes. Examination of placentas after delivery indicated an increase in size and weight from 550 g to 800 g in both regions. Histological examination revealed basal deciduitis and/or chorioamnionitis, with an associated inflammatory cell infiltrate in the peripheral and ventral parts of the placenta and in the placental membranes in 45.5% of cases. A lymphocytic infiltrate was present in the basal aspects of the placenta, and this was considered to be indicative of an immunological reaction by the mother against the fetus and its membranes at certain stress points at the placental site.

There were also hemodynamic disturbances of the placental circulation, causing hemorrhagic placental infarction, pseudoinfarction in basal and chorionic membranes and in the intervillous space, thrombosis and hemorrhage in the basal plate, and dystrophic changes in the chorionic syncytium. These caused compensatory adaptive changes of differing magnitude in all cases as evidenced by proliferative processes detected on electron microscopy. Capillary hyperplasia was seen, and there were changes in the organelles of the chorionic syncytium. Syncytial knots in the placenta were produced by proliferation of syncytial tissue with signs of dystrophia. There was a reduction in the amount of periodic acid-Schiff (PAS)-staining material in the placenta. Histochemical studies showed changes in energy metabolism. The structural changes observed in the placenta were multiple, varied and nonspecific.

Peripheral Blood of Neonates

Neonatal blood was examined on the first and fifth days of life to reflect the maximum stressful adaption to the new environment and the possibility of marrow suppression following the period of maximum hematopoietic activity, respectively. Hyperproduction of red blood cells and hemoglobin in response to stress situations was seen in babies in their first year of life following the accident. In 1990, erythropenia, monoblastosis, anisocytosis, and poikilo-

cytosis was found in the first day of life, and these changes were progressive till the end of the early neonatal period (day 5). Thrombocytosis was present in 17% of day 1 neonates in 1987, however, by 1990, 29% of the newborn babies in their first day of extrauterine life had thrombocytopenia.

In 1990, the white cell numbers in peripheral blood of day 1 neonates were 60% lower than normal values. There were signs of irritation and destruction of lymphocytes as evidenced by mitosis, toxic granularity, Gumprecht shadows, and plasma cells. These abnormalities had increased 3-fold by day 5, at which time a pronounced leucopenia was detected.

Conclusion

We carried out an extensive and complex investigation of pregnant women and their offspring after the accident at Chernobyl in April 1986 and calculated that the health of the mothers, fetuses and children differed significantly from the physiological norm. There was a specific complex of adaptational and pathological abnormalities of various organs and systems.

The female reproductive system itself remained intact, but defective compensatory and adaptational mechanisms of the mothers and fetoplacental units resulted in diseases of the neonates that are still, at present, progressing. The general deterioration of the health of mothers and children is similar in all the polluted areas of Russia, *viz.*, Belorussia and the Ukraine, and it must be concluded that this effect was caused by radiation, which triggered a complex pattern of bodily dysfunction.

It is difficult to interpret the exact significance of the accumulated data because there is no definite information concerning the effects of minor doses of radiation on humans, and there is uncertainty about significance of the signs, the time of their appearance and duration, their correlation with individual dose levels, and the exact levels of pollution. We need to analyze the less serious somatic effects of minor doses of radiation, including the various functional disorders of organs and systems, because these may be initial signs of disease, and the final outcome may also be radiation induced, although at a dose level which does not have immediate effects.

The disorders and diseases revealed by this survey make it necessary to undertake special programs of prophylaxis and treatment in the population groups affected by radioactive contamination. Social measures are required to prevent prenatal abnormalities by way of optimizing conditions for the protection of the fetoplacental complex. This is essential to reduce the hazardous consequences of the Chernobyl accident and to preserve the health of posterity.